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Feasibility of Improving the Economic Return from the Gulf of Mexico Brown Shrimp Fishery

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Abstract.—A bioeconomic model was developed to investigate the feasibility of improving the economic return from the fishery for brown shrimp *Penaeus aztecus* through cooperative federal and state management closures in the U.S. Gulf of Mexico. Four different closure periods were simulated with the model. The closure options were evaluated for Texas only (current condition) and for the entire U.S. Gulf of Mexico (proposed condition). The model provided an accurate biological simulation of the brown shrimp fishery in the Gulf of Mexico. Each of the evaluated closures gave positive net profits to the fishery as a whole. However, these benefits were mainly for larger vessels (>50 ft in length). None of the proposed closures increased the profits for boats (undocumented vessels of unknown lengths), and only some closures increased the profits for smaller vessels (≤50 ft in length).

The Gulf of Mexico is the major U.S. production area for shrimp and accounts for approximately 70% of the total weight and 80% of the total value of shrimp landed in the United States (Holliday and O'Bannon 1991). Average annual commercial shrimp catch during 1980–1990 was 119,251 tons (whole weight), with an annual value of US$417 million. The largest harvest occurred in 1986 (152,020 tons; $565 million), while the lowest catch was in 1980 (95,564 tons; $321 million). Nine shrimp species contribute to the fishery; however, *Penaeus* spp. constitute over 97% of the commercial harvest. On the average, brown shrimp *P. aztecus* account for 58% of the harvest, white shrimp *P. setiferus* for 31%, and pink shrimp *P. duorarum* for 8%. The other six species (*Hymenopenaeus robustus, Sicyonia brevirostris, S. doralis, Trachypenaeus constrictus, T. similis*, and *Xiphopenaeus kroyeri*) account for a combined 3% of the total. The highest densities of brown shrimp occur off the Texas–Louisiana coast, the highest concentration of white shrimp occurs off the Louisiana coast, and the highest densities of pink shrimp occur off southwest Florida (Klima 1989).

In 1976 the United States extended its jurisdiction over fisheries, exclusive of tuna, to 200 nautical miles. The U.S. Congress opted for regional management of these fisheries, with the U.S. Gulf of Mexico selected as one of eight jurisdictional regions. Gulf fisheries within the territorial seas continued to be managed by individual states, while fisheries within the exclusive economic zone (EEZ) were managed by the National Marine Fisheries Service (NMFS), with management planning authority delegated to the Gulf of Mexico Fishery Management Council (GMFMC) (Leary 1985).

A fishery management plan for Gulf shrimp was implemented in 1981. The principal objectives of the shrimp management plan are to optimize the yield of shrimp recruited to the fishery and to reduce the discard of undersized shrimp. Presently, a state–federal cooperative shrimp closure exists to fulfill these objectives for the brown shrimp fishery off the state of Texas (Klima 1989).

Brown shrimp spawn in offshore waters of the Gulf of Mexico, and the postlarvae begin entering estuaries in February and continue through April. Postlarvae use the estuary as a nursery, eventually migrating back into offshore waters as subadults. While in the bays, juvenile shrimp are harvested by recreational and commercial fishing during the spring and early summer months. Emigration of subadults to offshore waters begins in May and ends in August, with peak emigration occurring from May through early July. The Texas closure increases the overall yield to the fishery by taking advantage of the brown shrimp life cycle. This is accomplished by reducing offshore fishing effort on rapidly growing juvenile and subadult shrimp from mid-May through mid-July. Research has shown that the closure (from beach to 200 nautical miles) provides a monetary benefit to the fishery each year (Klima et al. 1982; Nance et al. 1990). The ex-vessel value of the fishery is increased because larger, higher-priced shrimp are caught.

In January 1990, the GMFMC requested that NMFS investigate the feasibility of improving economic returns from the brown shrimp fishery

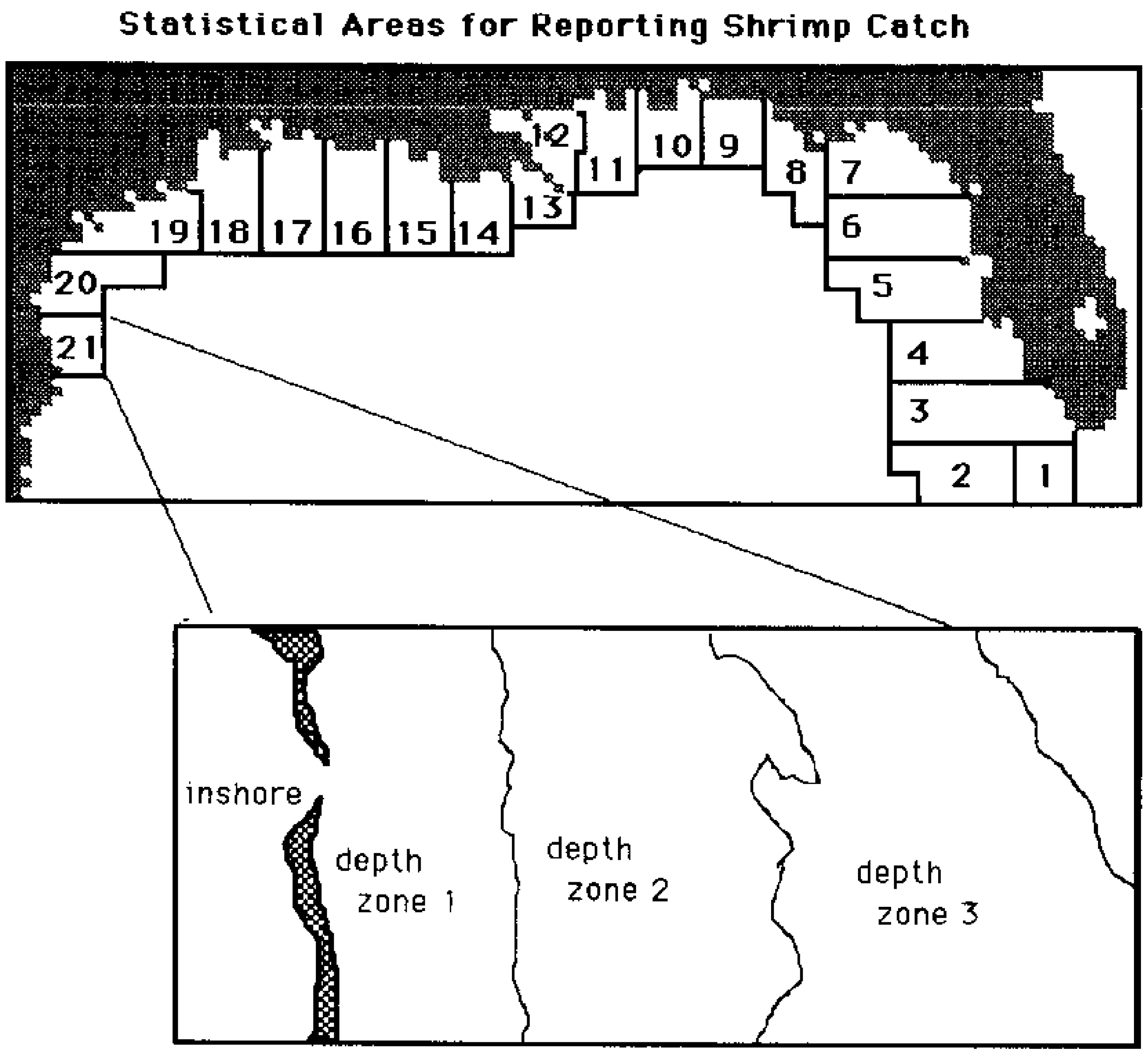

FIGURE 1.—Diagram of Gulf of Mexico brown shrimp fishery statistical areas and depth zones.

through cooperative management measures with Louisiana and other Gulf Coast states. We developed a simulation model to study the impact of closure options on the brown shrimp fishery. As with the Texas closure, the basic premise of the model was that a prohibition on fishing for emigrating juvenile brown shrimp would allow them to grow to a larger and more valuable size. The complete analysis involved four phases: (1) construction of the biological model to simulate yields in numbers and pounds of shrimp; (2) calculation of revenues from simulated landings using a regional price structure; (3) determination of fishing costs based on published cost information and data regarding the size of the fishery (i.e., number and type of fishing vessels); and (4) simulation of four closure options for different time periods and regional areas within the Gulf of Mexico. This paper summarizes the results of these closure simulations and discusses their implications for management options for the brown shrimp fishery.

Methods

General Model Development

The U.S. Gulf of Mexico was divided into three geographic areas during model development and analysis using statistical subareas and depth zones established by NMFS for summarization of shrimp catch and effort data (Figure 1). These geographic regions included the west Gulf (subareas 18–21, Texas), the northwest Gulf (subareas 11–17, Louisiana and Mississippi) and the northeast Gulf (subareas 7–10, Alabama and north Florida). Although it would have been desirable to break the U.S. Gulf of Mexico into units by individual states, functionally these three units represented the best biological partitions. Subareas 18–21 were kept together because an offshore shrimp closure already exists in this region. Subareas 11–17 represented a major brown shrimp harvesting area, and subareas 7–10 delineated an area of low brown shrimp harvest.

Each of these geographic locations was subdivided into three depth zones. The first zone (inshore) included all the bays and estuaries. The second zone (nearshore) comprised the area from the beach out to a depth of 10 fathoms (fm). The third zone (offshore) contained the area with a water depth greater than 10 fm.

The basic functional component of the model is described in Figure 2. It is similar in design and structure to the bioeconomic fishery simulation model developed by Grant et al. (1981). However, our model is based on an age-structured population, and size considerations are implicitly modeled within the age structure. There is a compartment for each combination of age-class (0 through 17 months, in half-month intervals), geographic

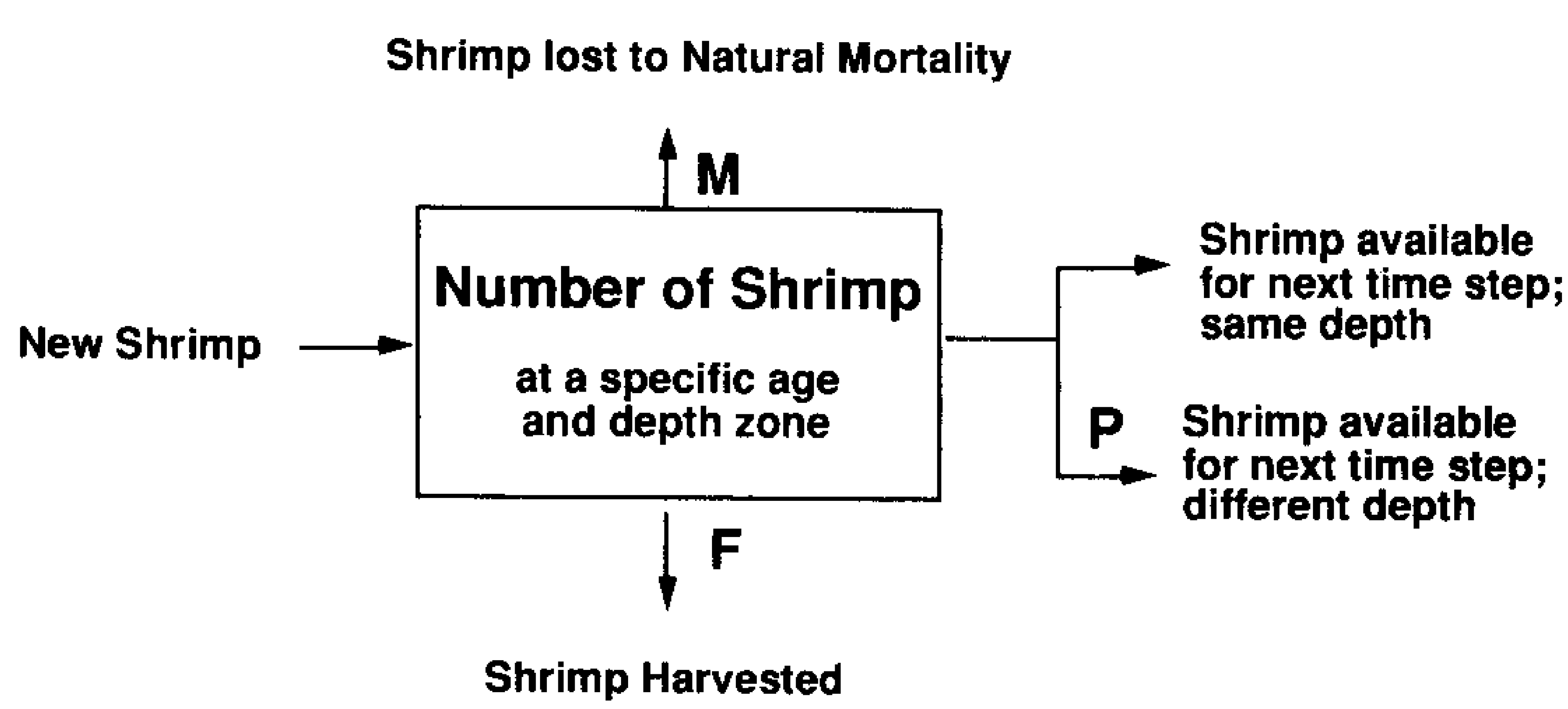

FIGURE 2.—Basic functional unit incorporated in the biological portion of the model; M is monthly instantaneous rate of natural mortality, F is monthly instantaneous rate of fishing mortality, and P is perpendicular-to-shore migration rate.

area (Texas, Louisiana–Mississippi, and Alabama–north Florida) and depth zone (inshore, nearshore, and offshore). The functional concept behind the model is: (1) during each semimonthly time interval new shrimp move into an age compartment box; (2) instantaneous natural and fishing mortalities are applied to these shrimp; and (3) all remaining shrimp increase in age and move into the next age compartment box as new shrimp.

Biological Data Input

Five basic data requirements were necessary for model development. These included: (1) monthly recruitment values of age-0 shrimp entering into the fishery, (2) initial population size estimates for each age-class at the beginning of the simulation, (3) monthly instantaneous rate of natural mortality (M), (4) monthly instantaneous rate of fishing mortality (F), and (5) perpendicular-to-shore migration rates from inshore bays to offshore waters of various bimonthly cohorts.

Current estimates of monthly instantaneous rate of natural mortality (M) for brown shrimp range between 0.20 and 0.35, with a median of 0.275 (Nance 1989). Since there is little justification for narrowing the range, the median was considered the best estimate and was used in the simulation model.

Virtual population analysis (VPA), based on catch statistics from the brown shrimp fishery (1960–1989), was used to produce estimates of both fishing mortality rates and number of shrimp in each semimonthly age-class (age 0 through age 17) for the selected geographic location (Ricker 1975; Nance 1989). In this analysis, age-0 shrimp have a minimum size of 45 mm tail length. Thus, initial population values for each age-class, semimonthly recruitment levels of new shrimp entering the fishery, and semimonthly F by age-class were obtained from the VPA procedure and used as data input in the simulation model. The VPA results from April 1988 through March 1989 were selected for input because they reflected the most recent fishery data without a 200-mile closure off Texas. These data represent the baseline values for all closure simulations.

Catch per unit of effort (CPUE) by size-class, obtained from fishery dependent statistics during 1986–1988, was summarized by month, geographic location, and depth. A table of CPUE by age was constructed for each month, area, and depth combination. Percentage of total brown shrimp population within each depth zone was calculated for each age-class and month. These data were then utilized to partition the initial age-class population groups into their various depth components and to estimate migration rates to offshore waters in the following manner. Inshore and offshore population estimates were separately plotted for each monthly cohort, with percent composition as the dependent variable (y-axis) and age as the independent variable (x-axis). Regression analysis was used to estimate the slope of the line (linear or curvilinear, based on functional form, with the smallest sum of squared residuals between actual and predicted values) through the data. The line through the inshore data represented the emigration rates of shrimp leaving the inshore waters, and the line through the offshore data represented the migration rate of shrimp entering offshore waters. Values for the nearshore area were the fraction of the population not in the other two areas. Migration rates were calculated for the April, May, June, July, and August cohorts in each geographic location. August migration rates were used for the September–March cohorts in each location.

The biological data inputs allowed the model to simulate the number of shrimp harvested by age-class. Conversions obtained from growth equations (Klima et al. 1987), were used to group shrimp into standard size-classes, and yield in pounds was calculated for the various harvest levels. Total Gulf of Mexico yields were obtained by adding the yields from each of the three geographic locations.

Revenue Data Input

Value of the harvested shrimp was established for each regional area by determining the average monthly price per pound for each of the size-classes. Monthly prices were obtained for the 1986–1988 period, standardized into 1989 dollars by means of annual consumer price index values, and then averaged to obtain the mean annual price per pound for each size-class in each regional area. We felt that applying annual price values to monthly shrimp catch was better than using monthly price values. The monthly price changes in response to a closure are unknown, but the overall mean annual prices should not be affected by a particular closure. Once the shrimp prices were obtained, revenues were calculated for each of the closure options.

Model Verification

Baseline simulations were performed to generate catch and revenues for each regional area. Outputs from baseline simulations were compared with

Gulf of Mexico catch statistics to check for discrepancies between actual landings and revenues and those generated by the simulation model for April 1988–March 1989. Differences between predicted and actual yields reflect the degree of uncertainty. Although a large difference would indicate a major degree of uncertainty and invalidate the model, a small difference would tend to validate the model.

Economic Data Input

Six basic data requirements were needed to develop the economic portion of the model that determines vessel owner profit. These data, summarized by area and month, included: (1) maximum number of full-time vessel equivalents, (2) partitioning of total monthly F into three sub-F values (one for each of the three vessel classes discussed below), (3) fixed vessel cost, (4) variable vessel cost (also known as effort cost), (5) number of crew and crew share, and (6) packing charges at seafood processing houses where the shrimp are unloaded.

The maximum number of full-time vessel equivalents is defined as the total number of vessels needed to catch the reported amount of shrimp, if each vessel fished full-time (24 h/d) and each vessel always experienced the average CPUE for the location in question. Full-time vessel equivalents were calculated for each region on a monthly basis, and the largest number was used for the maximum number of vessels in that given area. Three full-time vessel equivalent categories were introduced: undocumented vessels of unknown length (termed boats; usually fishing inshore waters), documented vessels 50 ft in length or shorter (usually fishing inshore and nearshore waters), and documented vessels longer than 50 ft in length (usually fishing nearshore and offshore waters). The maximum number of monthly full-time vessel equivalents was calculated for each vessel category with 1986–1988 data. For undocumented vessels (boats) we used the following three equations.

$$\text{Mean days out/boat} = (20 \text{ trips/boat}) \times (\text{mean days out/trip}); \quad (1)$$

mean days out/trip is calculated from port agent interviews and 20 trips/boat is based on information from port agents.

$$\text{Mean effort/boat} = (\text{mean effort/days out}) \times (\text{mean days out/boat}); \quad (2)$$

mean effort/days out is calculated from port agent interviews and mean days out/boat is obtained from equation (1).

$$\text{Number of boats} = \frac{(\text{total effort})}{(\text{mean effort/boat})}; \quad (3)$$

total effort is calculated from port agent interviews (Nance 1992) and mean effort/boat is obtained from equation (2).

For documented vessels we used the following two equations.

$$\text{Mean effort/vessel} = (\text{mean effort/trip}) \times (\text{mean trips/vessel}); \quad (4)$$

both mean effort/trip and mean trips/vessel are calculated from port agent interviews.

$$\text{Number of vessels} = \frac{(\text{total effort})}{(\text{mean effort/vessel})}; \quad (5)$$

total effort is calculated from port agent interviews (Nance 1992) and mean effort/vessel is obtained from equation (4).

Monthly total F values for the fleet were partitioned into sub-F values, one for each vessel class, as follows: (1) fishery-dependent data from each geographic location during 1986–1988 were used to calculate average monthly catch by depth zone for each vessel size category; (2) average monthly CPUE values for the different depth zones were divided into the catch data (calculated in step 1) to obtain total monthly effort values for each of the three vessel classes in each depth zone; and (3) percentage of monthly effort in each depth zone was calculated for each vessel class. These percentages were multiplied by total monthly F rates to subdivide the F rates into the three vessel classes. Subdivided F rates allowed the yield (pounds by size group) to be divided among the three vessel categories. Changes in yield associated with the closures could be monitored for each vessel class and the effects summarized during analysis.

Variable vessel cost is the expense associated with catching shrimp. The 1970–1980 data provided by Ward (1988) were used in the analysis. These data are in the form of total annual cost per vessel (all shrimp species) for each vessel class by regional area. Since the disbursements were for all shrimp species, the cost totals in each vessel class and region were multiplied by the ratio of brown shrimp to total shrimp for the same categories to estimate the expense associated with the brown shrimp fishery alone. Inflation factors were used to put each annual value into 1989 units and an average expense for the 11 years of data was calculated. These brown shrimp variable vessel costs were multiplied by the maximum full-time vessel equivalents to calculate the total expense in each combination of vessel class and region. These values were divided by the total regional sub-F values to obtain an effort cost per F, which was input into the model.

Fixed vessel cost is the expense associated with a vessel, whether or not the vessel is used during the shrimping season. Since the shrimp fishery is considered to be in economic equilibrium (i.e., the costs expended in the fishery equal the revenue gained in the fishery), the annual fixed vessel costs were computed for each vessel class and region combination by subtraction of variable vessel costs from the calculated revenue.

Values for number of crew, crew shares, and packing charges were obtained from Griffin et al. (1993). The undocumented vessels have no crew members in the analysis and no crew share. Both documented vessel classes have two crew members in the simulation and the crew receives a 20% share of revenues. Packing costs (processing fee charged by a seafood processing house, usually on a per unit weight of shrimp basis) are not charged to undocumented vessels in the model, because they usually process the shrimp themselves (Griffin et al. 1993). The documented vessels are charged a packing fee of $0.10 per pound in the model.

Policy Analysis

Four different Gulf of Mexico closures were simulated with the model. The June and July time frame selected for these closure options was based upon the period of maximum brown shrimp population growth (Klima et al. 1987). The different closures were: (1) June 1–July 15 nearshore–offshore; (2) May 15–July 15 nearshore–offshore; (3) June 1–July 31 nearshore–offshore; and (4) June 1–July 15 nearshore–offshore in combination with an inshore area closure from May 15 through May 31. These four closure options were applied to subareas 18–21 (Texas) only and then to all subareas (north Florida through Texas). During analysis of the closures, each regional area could be considered independently or combined to observe effects over the entire Gulf brown shrimp fishery.

To simulate a closure, instantaneous fishing rates during the closure period were set to zero. Since the baseline conditions reflect the traditional openings of the fishery (May and June in subareas 7–10 and 11–17, and July for subareas 18–21), the intense opening effort levels and patterns were shifted to postclosure time periods. For example, in subareas 18–21 a large pulse of offshore fishing effort is observed during the reopening of the EEZ and territorial waters in mid-July. When a 60-d closure ending on July 31 was simulated, the intense fishing pulse was shifted to the new reopening on August 1.

For the Texas-only closure options, 13% of the baseline effort was shifted to the Louisiana–Mississippi area (subareas 11–17). Previous Texas closure analysis has revealed that fishing effort migrated eastward at this level (Nance et al. 1990). No effort was shifted to opened areas off Alabama and north Florida.

To evaluate the effects of the management closures, yield curves (pounds and revenue) were generated for each closure option by application of F-multipliers to the fishing mortality input vectors. Multipliers ranged in value from 0.0 to 2.0, in 0.2 increments. An F-multiplication of 1.0 equaled present levels of fishing intensity within the system, whereas a F-multiplication of 2.0 represented fishing effort twice the present level. All point estimates of changes in yield (pounds and revenue) with the management closures in effect are based on data generated with an F-multiplier equal to 1.0.

The effect of each management measure was considered only for a single year. The brown shrimp fishery is assumed to be at or near economic equilibrium under base conditions. That is, on the average, the total cost incurred by the fishery is equal to the total revenue generated by the fishery with base management options. Figure 3 depicts the base situation for the fishery; the total cost line intersects the baseline revenues at point A (F-multiplier of 1.0 in this model). The effect of each new management closure option can be seen by the increase in revenue corresponding to the baseline simulation (Figure 3). We assumed that base levels of fishing effort (point B) will not be significantly altered in the first year with any of these closures. The total cost line will increase or decrease depending on effort costs and the magnitude of the harvest because crew shares and packing cost change. Hence, the difference between the revenue at point C and the cost at point D is designated as the profit and is itemized in the results for each specific time and area closure.

Results

Model Verification

The model provided an accurate biological (catch and revenue) simulation of the brown shrimp fishery in the U.S. Gulf of Mexico. Only 1 year was

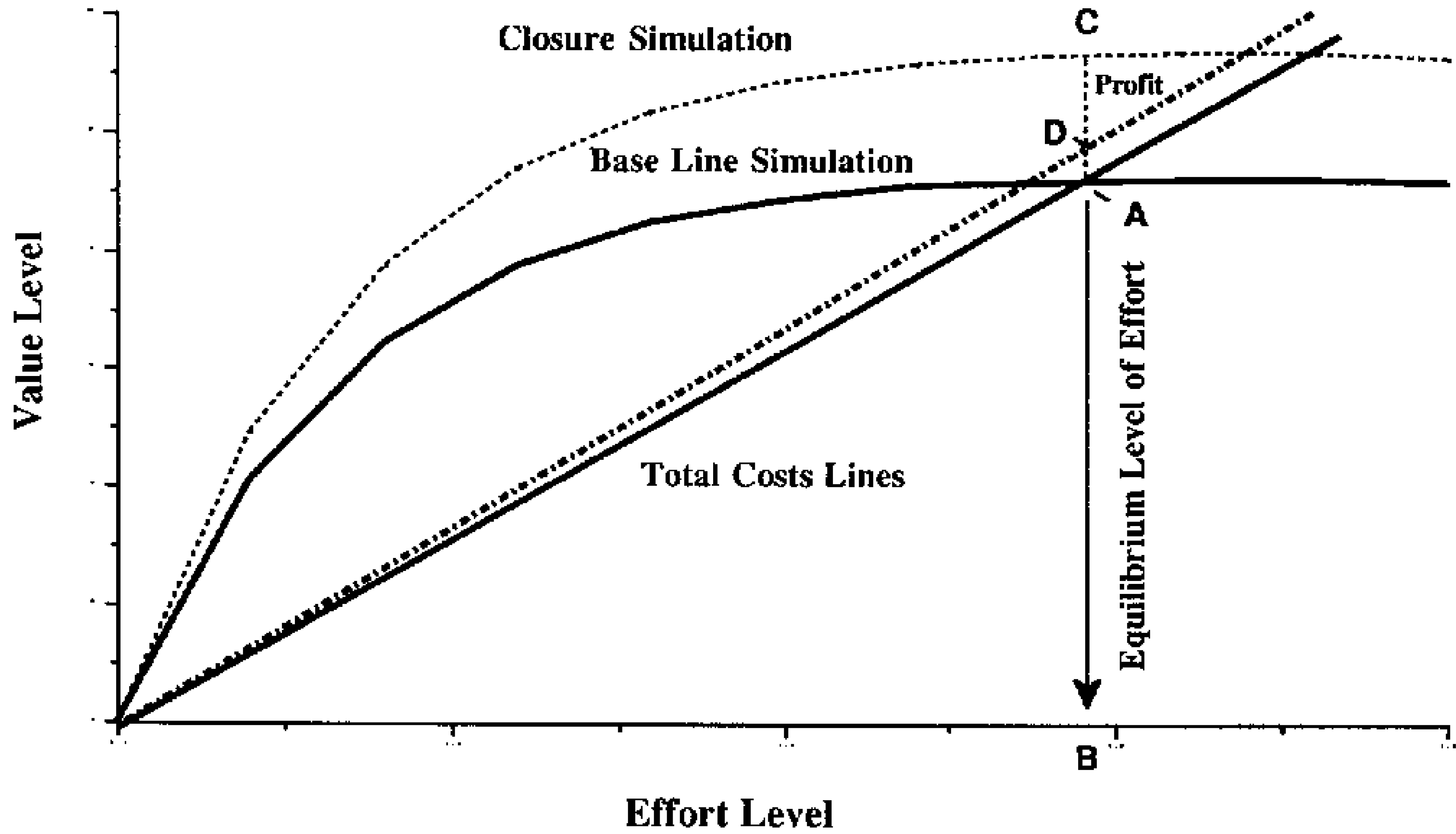

FIGURE 3.—Relationship of dollar yield (revenue) with present management (baseline) and optional management (closure). Point A represents the current economic equilibrium point, while point B depicts the amount of effort needed for equilibrium to occur in the fishery. Point C represents the expected revenue under new management option at old equilibrium effort level. Profit is the difference in revenue between point C and point D, which allows for the additional costs associated with higher harvest levels.

simulated because it is unknown what effects each closure would have on effort in subsequent years. The monthly landings for the simulated baseline mimicked the actual landings trend (Figure 4). No significant difference between actual and simulated landings was determined with a Kolmogorov–Smirnov test (Sokal and Rohlf 1981). Simulated Gulf landings peaked in June at 21.6 million pounds and reached a low of 0.7 million pounds in March. Actual landings for April 1988–March 1989 totaled 80.4 million pounds, whereas the simulated landings were 76.7 million pounds (5% difference).

A sensitivity analysis was undertaken to compare the effects of change in recruitment with change in pounds landed. The analysis revealed that there is a perfect ($R^2 = 1.0$) linear relationship between recruitment and pounds landed in all three areas. A 100% increase in recruitment produced a 52% increase in pounds landed in the Alabama–north Florida area, a 75% increase in pounds landed in the Louisiana–Mississippi area, and a 79%

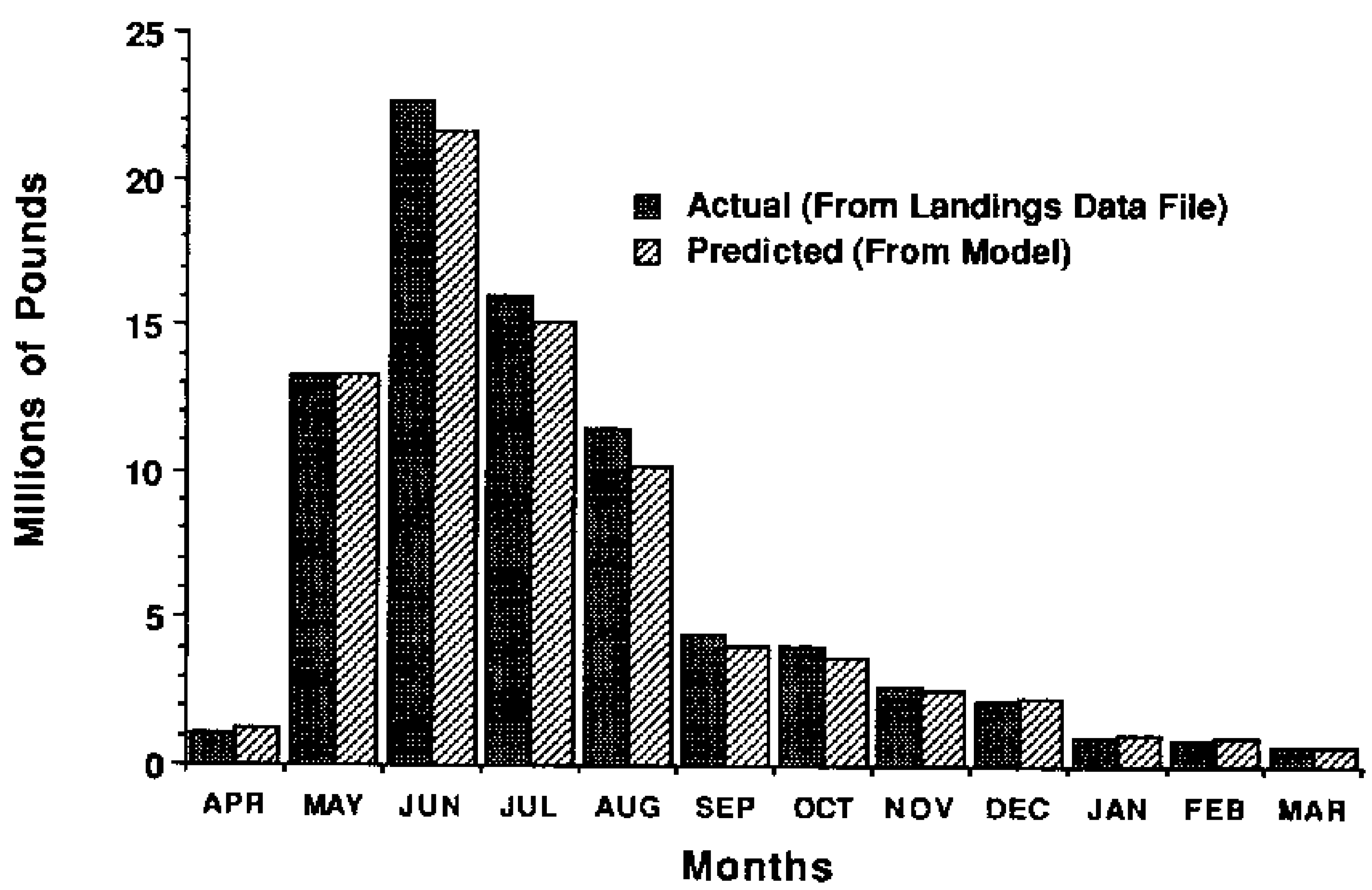

FIGURE 4.—Comparison of Gulf of Mexico brown shrimp landings predicted by modeling with actual fishery statistics for 1988–1989.

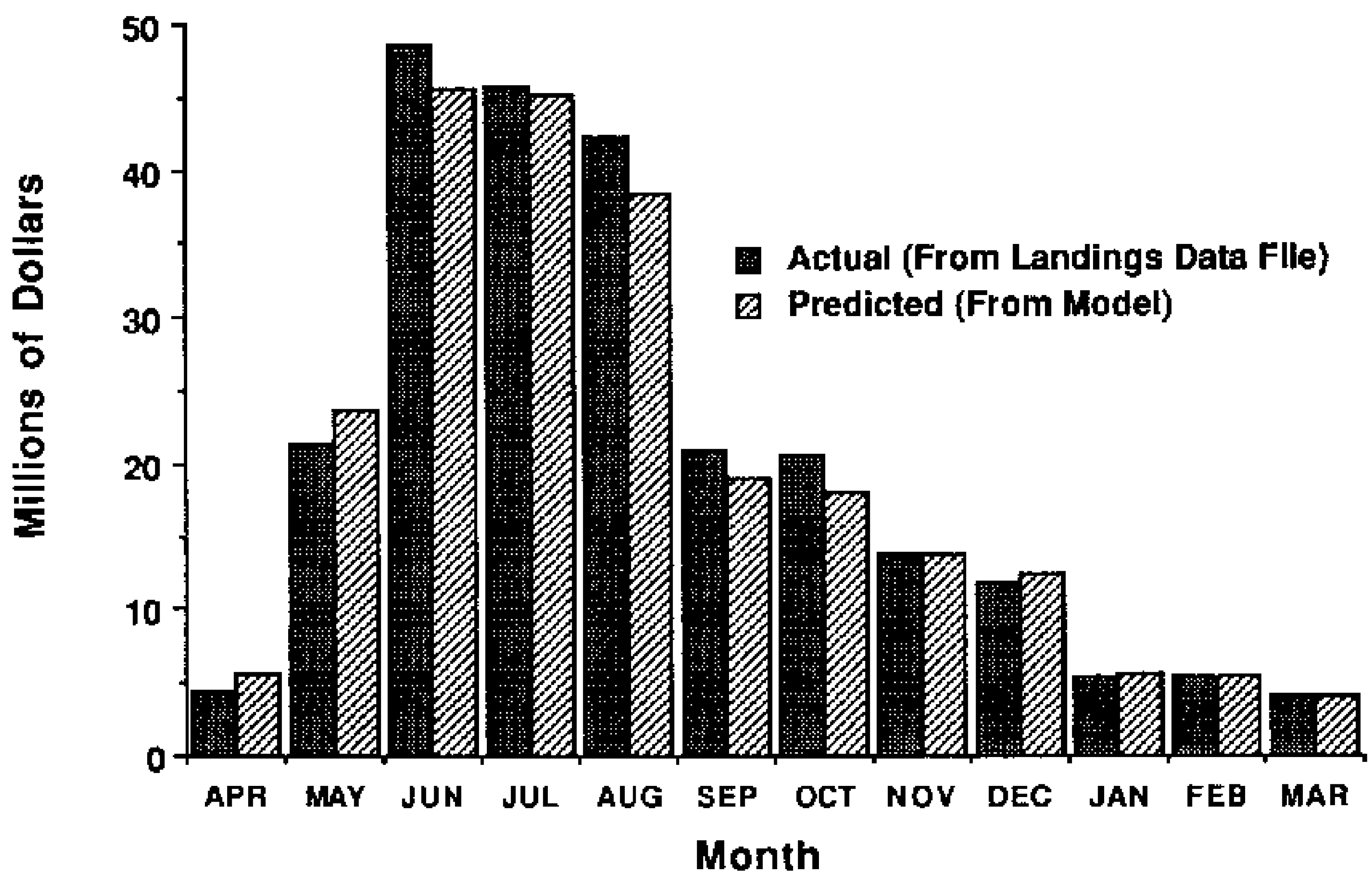

FIGURE 5.—Comparison of Gulf of Mexico brown shrimp revenue predicted by modeling with actual fishery statistics for 1988–1989.

increase in pounds landed in the Texas area. Overall, the total increase in pounds landed was 68%.

Revenue for the simulated baseline data also followed actual revenue values in each area (Figure 5). No significant difference between actual and simulated was determined with a Kolmogorov–Smirnov test. Monthly values ranged from a low of $4.0 million in March to a high of $45.6 million in June. Total revenue for the actual biological year was $244 million, with a simulation of $237 million (3% difference).

Annual catch-by-size comparisons from the various areas depict the overall precision of the baseline model (Figure 6). No significant difference between actual and simulated was determined with a Kolmogorov–Smirnov test. In each case, the actual and simulated catch-by-size values were comparable. This was an important result because fishery revenue is based on these catch-by-size values.

Policy Analysis

Results are presented for two spatial shrimp management closures (Texas area only and entire Gulf of Mexico), each with four temporal closure periods. The values obtained from the model for each of the closures are presented as departures from simulated baseline values and not as actual simulated values.

Texas closure only.—The first closure examined was a closure off the Texas coast during June 1–July 15 (Table 1), the time period for a typical closure (Klima et al. 1982; Nance et al. 1990). For the Texas area there was a decrease in total pounds (0.8 million). Although there was an increase in landings for the 15–40-count size-groups, less was taken in the 41-count and smaller size-groups (count size is a weight measure based on number of shrimp tails per pound; Table 2). Even with the overall decrease in pounds, there were increases in revenue ($2.3 million) and profit ($2.8 million) (Table 1). Both undocumented vessels (boats) and small vessels lost money ($4.9 million), while profits increased for large vessels ($7.8 million). This increase in profit for the larger vessels occurred because they have greater access to the larger shrimp found in the offshore waters. In the Louisiana–Mississippi area, a small increase was observed in total pounds (0.2 million). The increase came in the 51-count and smaller size-groups, with a decrease in the 50-count and larger size-groups (Table 2). This small increase in total pounds was accompanied by a decrease in both revenue ($0.4 million) and profit ($1.7 million). As in Texas, decreases were seen for boats and smaller vessels ($2.8 million), while an increase was observed for the larger vessels ($1.0 million) (Table 1). The Alabama–north Florida area was not affected by this closure. Hence, the overall impact on the Gulf of Mexico brown shrimp fishery was a catch decrease of about 0.7 million pounds. An increase in pounds landed from the 15–40-count size-groups was not large enough to make up for the decrease in the 41-count and smaller size-groups (Table 2). There was an overall increase in profit of $1.1 million. Larger vessels had an increase in profit of $8.8 million, while boats and smaller vessels experienced a decrease in profit ($7.7 million) (Table 1).

If the Texas closure was implemented 2 weeks earlier and reopened on the same day (May 15–July

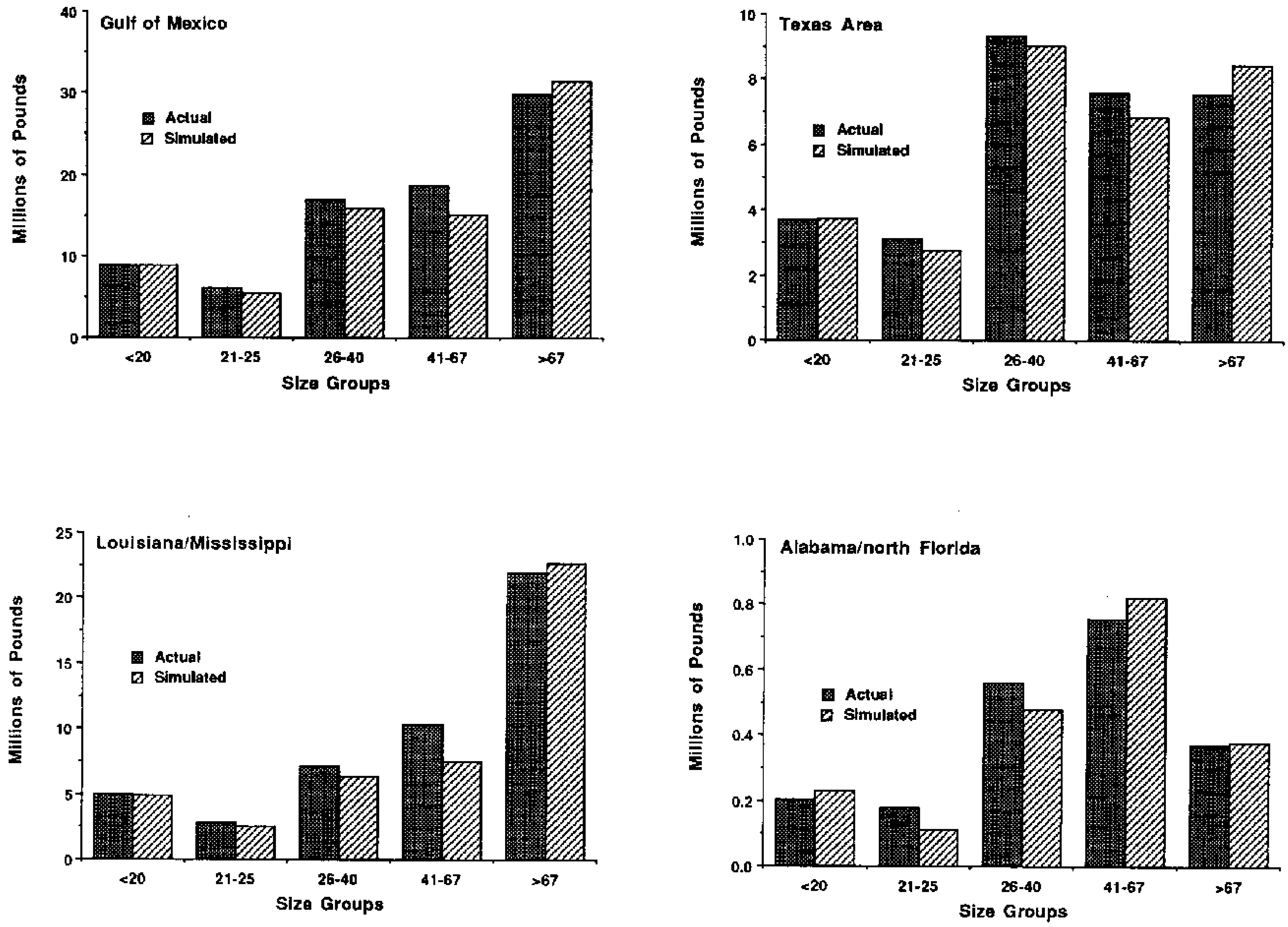

FIGURE 6.—Comparison of Gulf of Mexico brown shrimp catch by size predicted by modeling with actual fishery statistics for 1988–1989.

15), similar landings would be harvested. For the Gulf of Mexico there would be an overall increase in the landings from the 15–40-count size-groups, with a decrease in landings from the 41-count and smaller size-groups (Table 2). Louisiana–Mississippi would show increased landings from the 68-count and smaller size-groups, while Texas would show increases from the 15–40-count size-groups (Table 2). However, even with similar landings between this 60-d closure and the prior 45-d closure, the longer closure produced an overall increase in profit of $3.2 million (Table 1). Texas profit would increase around $5.7 million, while Louisiana–Mississippi would experience a decrease of about $2.5 million. Larger vessels in Texas would have an increase in profit of about $10.8 million, while in Louisiana–Mississippi the profit for the larger vessels would only increase $0.5 million. For the boats and smaller vessels in Texas there would be a decrease in profit of about $5.1 million, while in Louisiana–Mississippi the same vessel classes would experience a decrease in profit of about $2.9 million (Table 1).

On the other hand, if the closure began on June 1 and reopened 60 d later (July 31), the overall profit for the Gulf of Mexico would be higher than for the first closure option ($5.9 million instead of $1.1 million). Similar landings would again be harvested in the Gulf of Mexico (Table 1), with typical decreases in the 41-count and smaller size-groups and increases in the 15–40-count size-groups (Table 2). Louisiana–Mississippi would show increases in the 41-count and smaller size-groups and losses in the 40-count and larger size-groups. Texas areas would again experience decreases in landings from the 41-count and smaller size-groups and gains in the 15–40-count size-groups (Table 2). Overall profit in the Gulf of Mexico would be $5.9 million, with larger vessels showing an increase of $14.1 million and smaller vessels and boats experiencing a decrease of $8.2 million. In Texas, larger vessels would experience the greatest profit increase with $13.4 million, while in Louisiana–Mississippi the same vessel class would show an increase of $0.7 million. Smaller vessels and boats in Texas would show a profit

TABLE 1.—Predicted effects of four different Texas-only brown shrimp fishing closures on catch, revenue, and profit for each vessel type in each area. Values are deviations from simulated baseline.

Variable	Jun 1–Jul 15 closure	May 15–Jul 15 closure	Jun 1–Jul 31 closure	Combined closure[a]
		Texas		
Catch (lb)				
Boats	−1.25E+06	−1.54E+06	−1.53E+06	−1.84E+06
Vessels 0–50 ft	−7.63E+04	−9.37E+04	−1.10E+05	−1.12E+05
Vessels >50 ft	4.88E+05	9.12E+05	9.00E+05	2.08E+06
Total	−8.35E+05	−7.19E+05	−7.44E+05	1.31E+05
Revenue				
Boats	−5.02E+06	−5.25E+06	−5.48E+06	−5.15E+06
Vessels 0–50 ft	−2.92E+05	−2.92E+05	−3.38E+05	−2.61E+05
Vessels >50 ft	7.62E+06	1.03E+07	1.50E+07	1.60E+07
Total	2.31E+06	4.73E+06	9.20E+06	1.06E+07
Profit				
Boats	−4.88E+06	−5.10E+06	−5.36E+06	−4.84E+06
Vessels 0–50 ft	−6.81E+04	−1.57E+04	−3.04E+04	9.45E+04
Vessels >50 ft	7.75E+06	1.08E+07	1.34E+07	1.35E+07
Total	2.81E+06	5.71E+06	8.03E+06	8.71E+06
		Louisiana–Mississippi		
Catch (lb)				
Boats	3.26E+05	3.27E+05	3.63E+05	3.26E+05
Vessels 0–50 ft	3.90E+04	3.64E+04	4.93E+04	3.90E+04
Vessels >50 ft	−2.13E+05	−2.79E+05	−2.15E+05	−2.13E+05
Total	1.53E+05	8.41E+04	1.97E+05	1.53E+05
Revenue				
Boats	−2.47E+06	−2.55E+06	−2.45E+06	−2.47E+06
Vessels 0–50 ft	−1.56E+05	−1.61E+05	−1.53E+05	−1.56E+05
Vessels >50 ft	2.20E+06	1.81E+06	2.08E+06	2.20E+06
Total	−4.31E+05	−8.94E+05	−5.17E+05	−4.31E+05
Profit				
Boats	−2.61E+06	−2.77E+06	−2.68E+06	−2.61E+06
Vessels 0–50 ft	−1.51E+05	−1.81E+05	−1.78E+05	−1.51E+05
Vessels >50 ft	1.05E+06	4.84E+05	6.88E+05	1.05E+06
Total	−1.72E+06	−2.47E+06	−2.17E+06	−1.72E+06
		All areas combined		
Catch (lb)				
Boats	−9.21E+05	−1.21E+06	−1.17E+06	−1.51E+06
Vessels 0–50 ft	−3.74E+04	−5.72E+04	−6.02E+04	−7.26E+04
Vessels >50 ft	2.76E+05	6.33E+05	6.85E+05	1.87E+06
Total	−6.82E+05	−6.35E+05	−5.47E+05	2.84E+05
Revenue				
Boats	−7.49E+06	−7.80E+06	−7.92E+06	−7.62E+06
Vessels 0–50 ft	−4.48E+05	−4.53E+05	−4.91E+05	−4.17E+05
Vessels >50 ft	9.82E+06	1.21E+07	1.71E+07	1.82E+07
Total	1.88E+06	3.83E+06	8.68E+06	1.01E+07
Profit				
Boats	−7.49E+06	−7.87E+06	−8.03E+06	−7.46E+06
Vessels 0–50 ft	−2.19E+05	−1.97E+05	−2.08E+05	−5.66E+04
Vessels >50 ft	8.80E+06	1.13E+07	1.41E+07	1.45E+07
Total	1.09E+06	3.24E+06	5.87E+06	6.99E+06

[a] Jun 1–Jul 15 nearshore–offshore closure combined with a May 1–31 inshore closure.

decrease of around $5.4 million, and in Louisiana–Mississippi the decrease would be $2.7 million.

If the 45-d offshore closure in Texas (June 1–July 15) was combined with an inshore closure of Texas during the month of May (May 1–May 31), there would be a very small increase in overall pounds landed (0.3 million) but a large increase in both revenues ($10.1 million) and profit ($7.0 million) (Table 1). The increase in landings would be from the 15–40-count size-groups in Texas and the 51-count and smaller size-groups in Louisiana–Mississippi (Table 2). Although decreases were observed in the 41-count and smaller size-groups from Texas and the 41-count and larger size-groups from Louisiana–Mississippi, the decreases were not great enough to cause the overall landings to de-

TABLE 2.—Predicted effects of four different Texas-only brown shrimp fishery closures on catch sizes in each area. Values, in millions of pounds, are deviations from simulated baseline.

Baseline and closure	>116 count	81–116 count	68–80 count	51–67 count	41–50 count	31–40 count	26–30 count	21–25 count	15–20 count	<15 count
Texas										
Baseline	3.407	2.475	2.552	3.704	3.150	5.888	3.145	2.763	3.015	0.721
Jun 1–Jul 15 closure	−0.210	−0.456	−0.645	−0.864	−0.863	1.298	0.409	0.387	0.212	−0.103
May 15–Jul 15 closure	−0.318	−0.750	−1.040	−0.815	−0.826	1.791	0.585	0.489	0.269	−0.103
Jun 1–Jul 31 closure	−0.223	−0.459	−0.639	−1.852	−1.739	0.172	2.404	1.118	0.577	−0.103
Combined closure[a]	−1.540	−0.684	−0.790	−0.490	−0.594	2.385	0.875	0.680	0.394	−0.103
Louisiana–Mississippi										
Baseline	9.966	7.032	5.693	4.108	3.337	4.129	2.175	2.536	3.844	1.059
Jun 1–Jul 15 closure	0.122	0.209	0.068	0.028	−0.020	−0.117	−0.066	−0.032	−0.025	−0.015
May 15–Jul 15 closure	0.220	0.208	0.066	−0.024	−0.059	−0.155	−0.083	−0.041	−0.033	−0.015
Jun 1–Jul 31 closure	0.137	0.219	0.078	0.069	0.001	−0.111	−0.092	−0.049	−0.040	−0.015
Combined closure	0.122	0.209	0.068	0.028	−0.020	−0.117	−0.066	−0.032	−0.025	−0.015
All areas combined										
Baseline	13.502	9.630	8.374	8.286	6.835	10.336	5.480	5.411	7.038	1.828
Jun 1–Jul 15 closure	−0.088	−0.248	−0.577	−0.836	−0.883	1.182	0.343	0.355	0.187	−0.118
May 15–Jul 15 closure	−0.097	−0.542	−0.974	−0.839	−0.885	1.635	0.502	0.448	0.236	−0.118
Jun 1–Jul 31 closure	−0.086	−0.240	−0.561	−1.783	−1.738	0.061	2.312	1.069	0.537	−0.118
Combined closure	−1.418	−0.476	−0.722	−0.462	−0.614	2.268	0.809	0.648	0.369	−0.118

[a] Jun 1–July 15 nearshore–offshore closure combined with a May 1–31 inshore closure.

crease below baseline levels. Overall, the Gulf of Mexico would experience an increase in profit of $7.0 million. The larger vessels fishing off Texas would have increases in profit of $13.5 million, while larger vessels off Louisiana–Mississippi would experience increases in profit of $1.0 million. Smaller vessels and boats would again experience a decrease in profit in the Gulf of Mexico of $7.5 million. The vessels fishing in Texas would lose $4.9 million, while those in Louisiana would lose $2.9 million (Table 1).

Each of the four closure simulation options have situations which benefit some groups over others. None of the closures changed total Gulf of Mexico landings more than 0.7 million pounds as compared with the baseline data. The three closures that affected only the nearshore–offshore each had associated losses of between 0.5 and 0.7 million pounds. Only the combined inshore and nearshore–offshore closure had a positive effect on landings (0.3 million). This combined closure would result in the greatest overall profit to the Gulf of Mexico shrimp fishery ($7.0 million) and to the large vessels ($14.5 million) (Table 1). The combined closure also caused the least overall profit loss for the smaller vessels and the boats, with a decrease of only $7.5 million. For the boats and smaller vessels fishing in Texas, the combined closure provided the least decrease in profit ($4.7 million), while the delayed offshore opening (June 1–July 31) provided the greatest decrease in profit ($5.4 million). For boats and smaller vessels fishing in Louisiana–Mississippi, both the combined closure and the 45-d (June 1–July 15) closure provided the minimum decrease in profit ($2.8 million), while the 60-d closure (May 15–July 15) provided the greatest decrease in profit ($3.0 million).

Simultaneous gulfwide closures.—A simultaneous Gulf of Mexico brown shrimp fishery closure of 45 d (June 1–July 15) was investigated with the model. In the Texas area there would be net loss of pounds (0.8 million), while in Louisiana–Mississippi and Alabama–north Florida net gains were obtained (0.7 and 0.6 million pounds, respectively; Table 3). There were gains in the 15–40-count size-groups for Texas, the 21–40 and 51–67-count size-groups for Louisiana–Mississippi, and in the 15–40-count size-groups for Alabama–north Florida (Table 4). For the Gulf of Mexico most of the decreases occurred in the 41-count and smaller size-groups. Larger vessels in each area experienced excellent profit ($27.0 million overall), while the boats and smaller vessels in each area suffered profit losses ($15.9 million overall). All three areas showed increases in profit, with an overall increase of about $11.0 million (Table 3).

When the entire nearshore–offshore U.S. Gulf of Mexico was closed May 15 and reopened July 15, there was net gain in landings of 1.4 million pounds. In the Texas area there was a net loss of 0.7 million pounds, while in the Louisiana–Mississippi area there was a gain of 1.5 million pounds,

TABLE 3.—Predicted effects of four total Gulf of Mexico brown shrimp fishing closures on catch, revenue, and profit for each vessel type in each area. Values are deviations from simulated baseline.

Variable	Jun 1–Jul 15 closure	May 15–Jul 15 closure	Jun 1–Jul 31 closure	Combined closure[a]
Texas				
Catch (lb)				
Boats	−1.25E+06	−1.54E+06	−1.53E+06	−1.84E+06
Vessels 0–50 ft	−7.63E+04	−9.37E+04	−1.10E+05	−1.12E+05
Vessels >50 ft	4.88E+05	9.12E+05	9.00E+05	2.08E+06
Total	−8.35E+05	−7.19E+05	−7.44E+05	1.31E+05
Revenue				
Boats	−5.02E+06	−5.25E+06	−5.48E+06	−5.15E+06
Vessels 0–50 ft	−2.92E+05	−2.92E+05	−3.38E+05	−2.61E+05
Vessels >50 ft	7.62E+06	1.03E+07	1.50E+07	1.60E+07
Total	2.31E+06	4.73E+06	9.20E+06	1.06E+07
Profit				
Boats	−4.88E+06	−5.10E+06	−5.36E+06	−4.84E+06
Vessels 0–50 ft	−6.81E+04	−1.57E+04	−3.04E+04	9.45E+04
Vessels >50 ft	7.75E+06	1.08E+07	1.34E+07	1.35E+07
Total	2.81E+06	5.71E+06	8.03E+06	8.71E+06
Louisiana–Mississippi				
Catch (lb)				
Boats	−3.05E+06	−3.52E+06	−3.56E+06	−3.30E+06
Vessels 0–50 ft	−2.88E+05	−2.72E+05	−4.95E+05	−2.46E+05
Vessels >50 ft	4.04E+06	5.34E+06	5.20E+06	6.11E+06
Total	7.09E+05	1.55E+06	1.15E+06	2.57E+06
Revenue				
Boats	−1.10E+07	−1.14E+07	−1.12E+07	−1.00E+07
Vessels 0–50 ft	−5.15E+05	−4.92E+05	−5.41E+05	−4.24E+05
Vessels >50 ft	2.31E+07	3.08E+07	3.05E+07	3.52E+07
Total	1.16E+07	1.90E+07	1.87E+07	2.48E+07
Profit				
Boats	−1.01E+07	−1.01E+07	−9.87E+06	−9.11E+06
Vessels 0–50 ft	−1.64E+05	7.10E+04	−5.67E+04	−7.51E+04
Vessels >50 ft	1.79E+07	2.47E+07	2.36E+07	2.76E+07
Total	7.65E+06	1.47E+07	1.37E+07	1.84E+07
Alabama–north Florida				
Catch (lb)				
Boats	−7.63E+05	−7.65E+05	−5.25E+04	−6.37E+04
Vessels 0–50 ft	−3.82E+04	−3.82E+04	1.16E+04	4.04E+03
Vessels >50 ft	1.38E+06	1.40E+06	8.47E+04	6.70E+03
Total	5.81E+05	5.94E+05	4.37E+04	−5.29E+04
Revenue				
Boats	−4.80E+04	−4.36E+04	−5.90E+05	−8.04E+05
Vessels 0–50 ft	−4.61E+04	−3.49E+04	−2.86E+04	−4.12E+04
Vessels >50 ft	9.74E+04	1.41E+05	2.01E+06	1.40E+06
Total	3.27E+03	6.21E+04	1.39E+06	5.53E+05
Profit				
Boats	−7.15E+05	−7.22E+05	−5.38E+05	−7.48E+05
Vessels 0–50 ft	7.90E+03	−3.31E+03	−2.55E+04	6.15E+03
Vessels >50 ft	1.28E+06	1.26E+06	1.69E+06	1.35E+06
Total	5.78E+05	5.32E+05	1.13E+06	6.04E+05
All areas combined				
Catch (lb)				
Boats	−5.06E+06	−5.82E+06	−5.14E+06	−5.20E+06
Vessels 0–50 ft	−4.03E+05	−4.04E+05	−5.93E+05	−3.54E+05
Vessels >50 ft	5.91E+06	7.65E+06	6.19E+06	8.20E+06
Total	4.55E+05	1.42E+06	4.49E+05	2.65E+06
Revenue				
Boats	−1.61E+07	−1.66E+07	−1.73E+07	−1.60E+07
Vessels 0–50 ft	−8.54E+05	−8.19E+05	−9.07E+05	−7.26E+05
Vessels >50 ft	3.09E+07	4.12E+07	4.75E+07	5.26E+07
Total	1.39E+07	2.38E+07	2.93E+07	3.59E+07
Profit				
Boats	−1.57E+07	−1.59E+07	−1.58E+07	−1.47E+07
Vessels 0–50 ft	−2.24E+05	5.19E+04	−1.13E+05	2.56E+04
Vessels >50 ft	2.70E+07	3.67E+07	3.87E+07	4.24E+07
Total	1.10E+07	2.09E+07	2.28E+07	2.77E+07

[a] Jun 1–Jul 15 nearshore–offshore closure combined with a May 1–31 inshore closure.

and in Alabama–north Florida there was a gain of 0.6 million pounds (Table 3). Most of the gain occurred in the 15–40-count size-groups, while most losses were experienced in the 68-count and smaller size-groups (Table 4). The overall profit gain for the shrimp fishery with this 60-d closure was $20.9 million. This was almost double the value from the 45-d closure discussed above. Large vessels would show a profit gain of $36.7 million, while boats and smaller vessels would experience a decrease of $15.9 million (Table 3). Profit for large vessels would increase about $10.8 million off the Texas coast, $24.7 million off the Louisiana–Mississippi coast, and $1.3 million off the Alabama–north Florida coast. Boats and small vessels showed decreased profit in all three areas, with the largest decrease occurring in the Louisiana–Mississippi area ($10.1 million).

If the closure began on June 1, and remained in effect through July 31, large profit would be the result even though landings would not be altered to any great extent (Table 3). Overall, there would be a 0.5 million pound increase in landings, with a decrease off the Texas coast (0.7 million pounds) and increases off both the Louisiana–Mississippi coast (1.1 million) and the Alabama–north Florida coast (43.7 thousand) (Table 3). Landings would be increased in the 15–40-count size-groups off the Texas coast, in the 21–40-count size-groups off the Louisiana–Mississippi coast, and in the 15–30-count size-groups off the Alabama–north Florida coast (Table 4). For the Gulf of Mexico there would a general decrease in the 41-count and smaller size-groups and an increase in the 15–40-count size-group. Total profit for the shrimp fishery would be $22.8 million, double the value obtained with the 45-d closure. Larger vessels would gain profit of about $13.4 million in Texas, $23.6 million in Louisiana–Mississippi and about $1.7 million in the Alabama–north Florida area. Boats and smaller vessels would have a general decrease in profit of $15.8 million.

If an inshore closure (May 1–May 31) were combined with the nearshore–offshore closure (June 1–July 15), profit would increase for the shrimp fishery because of an increase in landings of 2.6 million pounds (Table 3). This general increase in pounds would come mainly from 15–40-count size-groups (Table 4). Losses would occur in the 41-count and smaller size-groups off Texas, in the 68-count and smaller size-groups for the Louisiana–Mississippi area, and in the 41-count and smaller

TABLE 4.—Predicted effects of four different total Gulf of Mexico brown shrimp fishery closures on catch sizes in each area. Values, in millions of pounds, are deviations from simulated baseline.

Baseline and closure	>116 count	81–116 count	68–80 count	51–67 count	41–50 count	31–40 count	26–30 count	21–25 count	15–20 count	<15 count
				Texas						
Baseline	3.407	2.475	2.552	3.704	3.150	5.888	3.145	2.763	3.015	0.721
Jun 1–Jul 15 closure	−0.210	−0.456	−0.645	−0.864	−0.863	1.298	0.409	0.387	0.212	−0.103
May 15–Jul 15 closure	−0.318	−0.750	−1.040	−0.815	−0.826	1.791	0.585	0.489	0.269	−0.103
Jun 1–Jul 31 closure	−0.223	−0.459	−0.639	−1.852	−1.739	0.172	2.404	1.118	0.577	−0.103
Combined closure[a]	−1.540	−0.684	−0.790	−0.490	−0.594	2.385	0.875	0.680	0.394	−0.103
				Louisiana–Mississippi						
Baseline	9.966	7.032	5.693	4.108	3.337	4.129	2.175	2.536	3.844	1.059
Jun 1–Jul 15 closure	−1.715	−1.560	−1.400	0.458	−0.062	2.865	1.973	0.612	−0.100	−0.361
May 15–Jul 15 closure	−2.716	−2.084	−1.926	1.130	0.395	3.861	2.396	0.823	0.030	−0.361
Jun 1–Jul 31 closuer	−1.866	−2.361	−2.006	0.213	−0.282	3.711	3.133	1.006	−0.035	−0.363
Combined closure	−4.276	−1.383	−1.290	1.375	0.562	4.120	2.683	1.001	0.139	−0.361
				Alabama–north Florida						
Baseline	0.129	0.123	0.128	0.474	0.347	0.319	0.161	0.113	0.180	0.048
Jun 1–Jul 15 closure	−0.014	−0.028	−0.033	−0.170	−0.111	0.079	0.160	0.047	0.050	−0.010
May 15–Jul 15 closure	−0.015	−0.030	−0.036	−0.169	−0.111	0.083	0.162	0.047	0.050	−0.010
Jun 1–Jul 31 closure	−0.015	−0.038	−0.045	−0.194	−0.137	−0.065	0.333	0.097	0.116	−0.009
Combined closure	−0.019	−0.031	−0.036	−0.183	−0.122	0.083	0.164	0.050	0.052	−0.010
				All areas combined						
Baseline	13.502	9.630	8.374	8.286	6.835	10.336	5.480	5.411	7.038	1.828
Jun 1–Jul 15 closure	−1.940	−2.044	−2.078	−0.575	−1.036	4.242	2.542	1.046	0.161	−0.474
May 15–Jul 15 closure	−3.049	−2.863	−3.002	0.145	−0.542	5.735	3.142	1.360	0.348	−0.475
Jun 1–Jul 31 closure	−2.104	−2.858	−2.690	−1.833	−2.158	3.818	5.869	2.221	0.658	−0.474
Combined closure	−5.835	−2.098	−2.117	0.702	−0.155	6.587	3.722	1.730	0.584	−0.474

[a] Jun 1–July 15 nearshore–offshore closure combined with a May 1–31 inshore closure.

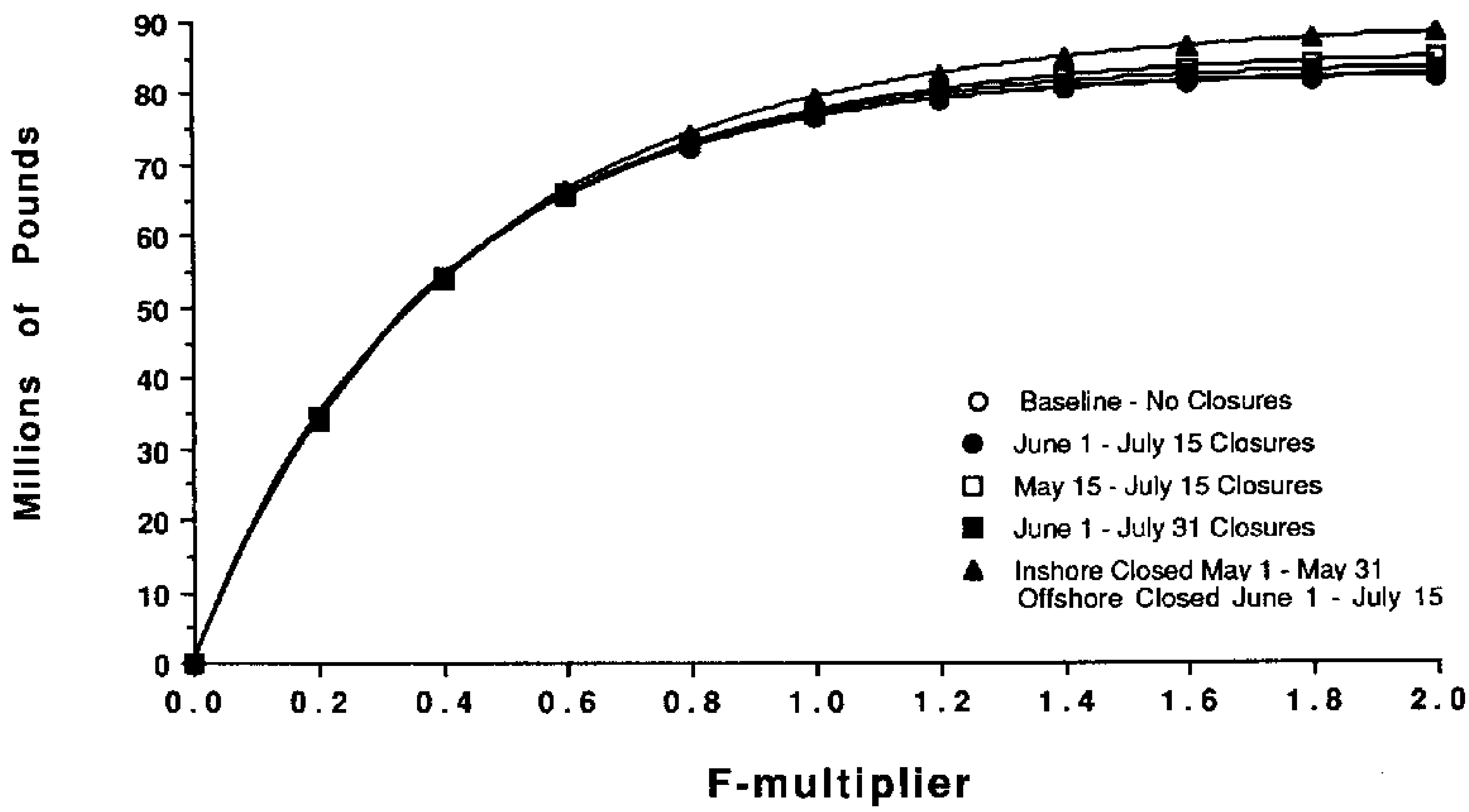

FIGURE 7.—Yield (pounds) curves for the different Gulf of Mexico brown shrimp fishery closure options.

size-groups for the Alabama–north Florida coast area. Overall, larger vessels would receive a gain in their profit of $42.4 million. The greatest proportion of this profit would go to the larger vessels fishing in the Louisiana–Mississippi area ($27.6 million), with the next greatest amount going to the vessels in Texas ($13.5 million), followed by the vessels fishing along the Alabama–north Florida coast area ($1.3 million). There would be a general decrease in profit for boats and smaller vessels of $14.7 million. Most of this decrease would occur in the Louisiana–Mississippi area ($9.2 million), with the Texas area next ($4.9 million), followed by the Alabama–north Florida area ($0.8 million).

Each of the four total Gulf of Mexico closures provides an advantage for one or more vessel types. None of the closures shows a great increase in the pounds landed when compared to the baseline data. The June 1–July 15 closure increased harvest the least (0.5 million pounds), while the combined closure stimulated harvest the most (2.6 million pounds). None of the closures produced a net decrease in the stimulated pounds landed compared to the baseline. Large vessels from all areas receive the greatest benefit in profit from the combined closure, although this vessel class showed a positive benefit in profit with all closure types. On the other hand, the boat and small vessel classes lost profit with most closure types. The smallest overall decrease came from the combined closure ($14.7 million), while the greatest decrease came from the June 1–July 15 closure ($15.92 million). However, the decrease in profit from the 45-d closure for these two vessel classes was only slightly greater than for the other two nearshore–offshore-only closures ($15.91 million and $15.85 million).

Discussion

This brown shrimp fishery model represents an accurate simulation of the present conditions in the U.S. Gulf of Mexico. Although many assumptions were made during the development of the model, each was generated with the best available information. We feel comfortable with the model because the simulation of baseline conditions for the 1988–1989 period generates approximately the same landings and revenue data as occurred in the actual fishery.

Comparative yield curves in both pounds and actual dollars (revenue), were developed for the entire Gulf of Mexico for each of the proposed closures in relation to the baseline condition. At the present level of fishing effort (i.e., F-multiplier of 1.0), these curves all indicate that any increase in fishing effort will eventually result in a slight increase in pounds (Figure 7), but a decrease in revenue (Figure 8). It would appear from these yield curves that we are at or near the maximum revenue that can be derived from the present stock under current price structures. Therefore, any increase in fishing effort will result in marginal increases in pounds but substantial decreases in revenue.

The model allowed for some shifts in fishing effort that would occur with the different types of

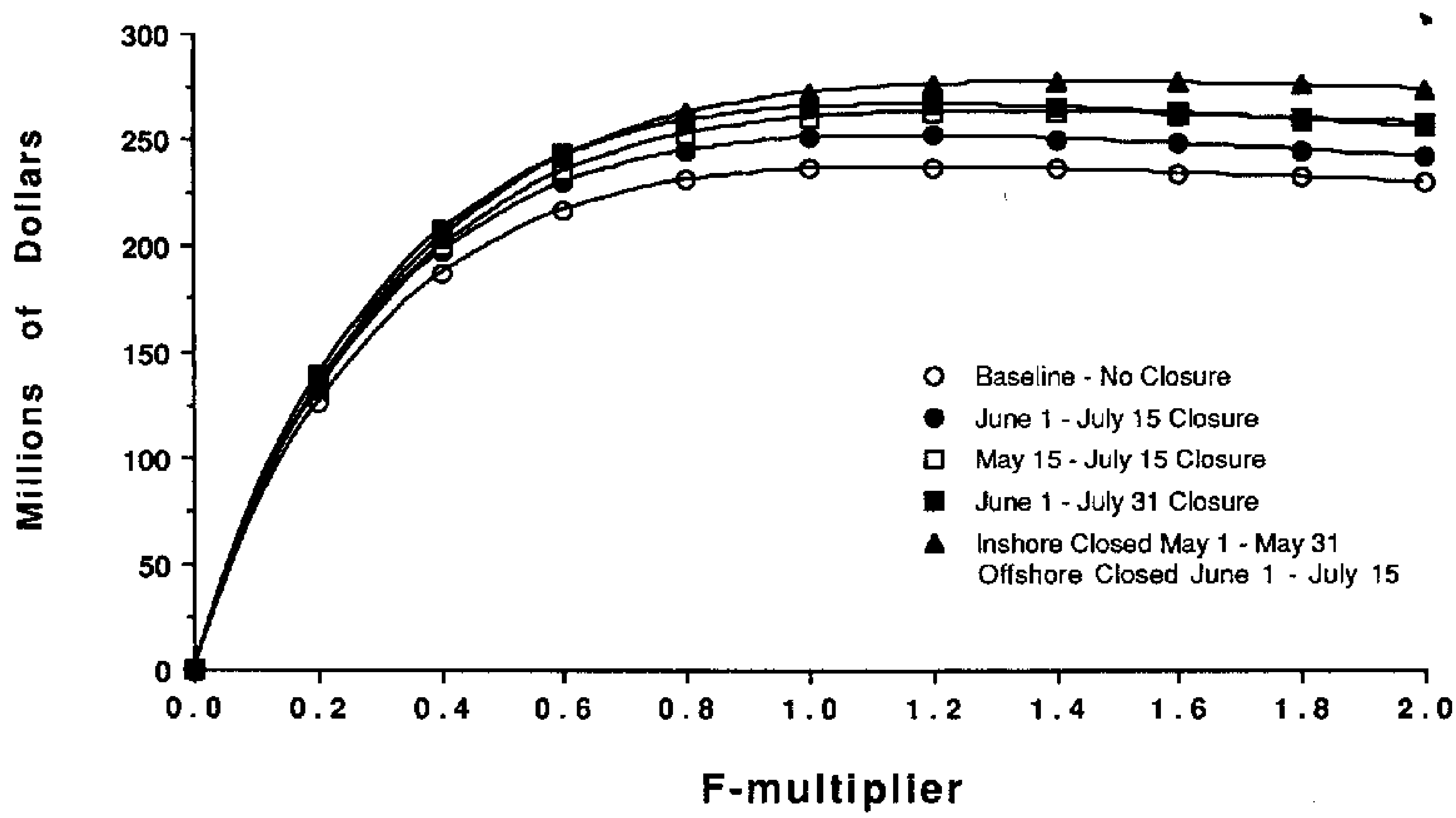

FIGURE 8.—Yield (revenue) curves for the different Gulf of Mexico brown shrimp fishery closure options.

closures. For example, we anticipated a 13% shift of Texas fishing effort to the Louisiana–Mississippi area because of the prohibition of fishing in Texas (Nance et al. 1990). The model accommodates these shifts, and the resultant figures indicated a decrease in revenue in Louisiana–Mississippi because of these shifts. We did not incorporate a shift of nearshore–offshore effort into the inshore fishing zones because most of the offshore vessels are incapable of fishing in shallow coastal inshore waters. Also, in some states, such as Texas, quad-rigged vessels (vessels with four fishing nets) are prohibited from fishing inshore unless they modify their fishing gear to meet the restrictions. Since these shifts to inshore areas are not considered, the impact to the inshore fisheries and subsequent yield and revenue to the inshore boats may be underestimated with the current model.

The inshore fishery in Texas, Louisiana, and Mississippi appears to have an impact on the total fishery in terms of both pounds and revenue (Table 3). As an example, the landings for Texas with the June 1–July 15 offshore closure was 0.84 million pounds below baseline, while the same offshore closure combined with an inshore closure from May 1–May 31 produced 0.13 million pounds above baseline, a decrease of 0.97 million pounds because of the inshore fishery (Table 3). The impact on profit is even greater with a $5.9 million change.

The same inshore effect is true for the Louisiana–Mississippi area. During the June 1–July 15 offshore closure, a 0.71 million pound increase over baseline is projected, but the yield is increased to 2.57 million pounds if there were a prior inshore closure from May 1–May 31. The economic effect is far greater because large quantities of small shrimp are usually harvested inshore before May 31, which results in a potential profit decrease of $10.8 million to the entire fishery ($7.6 million over baseline with nearshore–offshore-only; $18.4 million over baseline with combined closure). It is quite evident that the inshore fisheries have an economic impact on the present offshore fishery.

Our results clearly show benefits to be gained by any of the gulfwide closures. However, this was true primarily for the larger vessels. None of the closures increased profit for the boats, and only some of the closures increased profit for smaller vessels. The maximum overall benefit for the brown shrimp fishery as a whole would be derived from a combination closure. The Alabama–north Florida area does not contribute significantly to these gains and could be excluded from the closure area because relatively few brown shrimp are actually caught in this area, regardless of the type of management regime imposed.

The analyses presented in this paper suggest that the brown shrimp fishery in the Gulf of Mexico is currently growth overfished, if the management objective is to maximize the total dollar yield from the fishery. More management protection for shrimp during early life stages results in an increase in the dollar return from the fishery. The increase in profits, however, go to the larger offshore vessels, at the expense of the smaller inshore vessels.

If the GMFMC considers any of these types of management closures, we recommend that it develop an active planning group to design the implementation of such management measures. Without effective planning, it would be virtually impossible to insure that any closure could be implemented without major unrest. Consideration must be given to the social and economic impacts on packing, processing, distribution, and markets as well. Further, once the fishing community understands the profit that will be gained from these types of management measures, there will be rapid boat building and a major increase in fishing effort. Fishing effort will increase not only because of new vessels in the fishery, but also because the existing fleet will increase fishing intensity. The result will be a dissipation of profit after several years and the possibility of recruitment overfishing of the current shrimp stock. Even if vessel entry limits are in place, the increased fishing intensity alone will raise fishing costs and partially or completely dissipate the economic gains. Therefore, it is important that the GMFMC consider some form of effort control so that profit from such management measures will not be dissipated.

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References

Grant, W. E., K. G. Isakson, and W. L. Griffin. 1981. A general bioeconomic simulation model for annual-crop marine fisheries. Ecological Modelling 13: 195–219.

Griffin, W., H. Hendrickson, C. Oliver, G. Matlock, C. E. Bryan, R. Riechers, and J. Clark. 1993. An economic analysis of Texas shrimp season closures. U.S. National Marine Fisheries Service Marine Fisheries Review 54(3):221–228.

Holliday, M. C., and B. K. O'Bannon. 1991. Fisheries of the United States, 1990. U.S. National Marine Fisheries Service Current Fishery Statistics 9000.

Klima, E. F. 1989. Approaches to research and management of U.S. fisheries for penaeid shrimp in the Gulf of Mexico. Pages 87–114 *in* J. F. Caddy, editor. Marine invertebrates fisheries: their assessment and management. Wiley, New York.

Klima, E. F., K. N. Baxter, and F. J. Patella, Jr. 1982. A review of the offshore shrimp fishery and the 1981 Texas closure. U.S. National Marine Fisheries Service Marine Fisheries Review 44(9–10):5–15.

Klima, E. F., R. G. Castro Melendez, N. Baxter, F. J. Patella, Jr., T. J. Cody, and L. F. Sullivan. 1987. MEXUS–Gulf Shrimp Research, 1978–84. U.S. National Marine Fisheries Society Marine Fisheries Review 49(1):21–30.

Leary, T. R. 1985. Review of the Gulf of Mexico management plan for shrimp. Pages 267–274 *in* P. C. Rothlisberg, B. J. Hill, and D. J. Staples, editors. Second Australian National Prawn Seminar, NPS2. Cleveland, Australia.

Nance, J. M. 1989. Stock assessment for brown, white and pink shrimp in the U.S. Gulf of Mexico, 1960–1987. NOAA Technical Memorandum NMFS-SEFC-221.

Nance, J. M. 1992. Estimation of effort for the Gulf of Mexico shrimp fishery. NOAA Technical Memorandum NMFS-SEFSC-300.

Nance, J. M., E. F. Klima, E. Scott-Denton, K. N. Baxter, and F. J. Patella, Jr. 1990. Biological review of the 1989 Texas closure for the brown shrimp fishery off Texas and Louisiana. NOAA Technical Memorandum NMFS-SEFC-248.

Ricker, W. E. 1975. Computations and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada 191.

Sokal, R. R., and F. J. Rohlf. 1981. Biometry. Freeman, New York.

Ward, J. M. 1988. A synthesis of cost and revenue surveys for Gulf of Mexico shrimp vessels. U.S. Marine Fisheries Service Marine Fisheries Review 50(1):47–52.